High-Frequency Channel Characterization

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LONG-TERM GOALS

The long-term goals are to advance our understanding of the nature of high-frequency (8-50 kHz) sound propagation in the ocean waveguide, with emphasis on surface, bottom, and volume effects on the forward propagated field.

OBJECTIVES

The central purpose of this work is to learn as much as possible about the channel impulse response (or transfer function) and its dynamics. Ideally, we would like to characterize the behavior as a function of 1) source/receiver geometry, 2) arrival angle, 3) carrier (central) frequency, 4) ocean volume structure, 5) bottom type, and 6) boundary dynamics, including effects of surface waves and bubbles. The band of interest has a variety of applications, including mine countermeasures, tracking odontocetes in navy ranges, and bottom mapping; however, the core interest in this program is for acoustic communications.

APPROACH

The field effort this year focused on the Makai Experiment (http://www.hlsresearch.com/Makai) conducted in the Pacific Missile Range Facility off Kauai, Hawaii, with participation from about 30 scientists from the following institutions:

- Applied Physical Sciences *(Bruce Abraham)*
- Arizona State University *(Tolga Duman, Subhadeep Roy)*
- Heat, Light, and Sound Research, Inc.(*M. Porter, A. Abawi, P. Hursky, K. Kim, M. Siderius*)
- Naval Research Laboratory (*T.C. Yang, Wen-Bin Yang*)
- NATO Undersea Research Centre (*Thomas Folégot*)
- SPAWAR (*Keyko McDonald, Mark Gilchrist*)
- University of Algarve (*Sergio Jesus*)
- University of California, Marine Physical Laboratory (*Mike Buckingham, Heechun Song*)
- University of Delaware (*Mohsen Badiey*)
- University of New Hampshire (*Christian deMoustier, Barbara Kraft*)
- Woods Hole Oceanographic Institute *(Jim Preisig)*

Although virtually all of the work revolved around HF acoustics, the experiment joined together roughly a dozen P.I.'s interested in different aspects of the problem. A lot of effort was required to

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14. ABSTRACT
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15. SUBJECT TERMS

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organize things in terms of equipment used, deployment configurations, etc. to satisfy the desires of the individual programs. The overall experiment was organized into the following modules, representing the key interests of different participants:

- Oceanographic effects
    - Surface waves (**Surf)**
    - HF tomography (**Tomo**)
- Sediment acoustics
- Ambient Noise (**AN**)
- Transmission Loss (**TL**)
- Vector sensors (VecSen)
- Field Calibration and depth filtering (**Calib**)
- Acoustic Communications
    - Multiple-Input Multiple-Output (**MIMO**)
    - Multi-access communications (**MA**)
- Robotic Arrays
    - Glider array (**Glider**)
    - RHIB (Rigid Hull Inflatable Boat) array (**RHIB**)

WORK COMPLETED

Figure 1 shows some of the equipment that was deployed. Much of the equipment was new and therefore the Makai Experiment was initially an engineering test, although all of the equipment ended up collecting useful data (there were no catastrophic failures). In more detail:


Lubell broadband towed source. This was our first test with a Lubell projector. A tow frame was built by SPAWAR. The source provided low-frequency measurements (100-1000 Hz) used to test the Field Calibration concept in which HF measurements (which can be easily made with an AUV or glider) are extrapolated to LF for other systems applications.

The "Acoustic Communications and Data Storage Buoys". These systems from the Naval Research Laboratory drift freely but can be continually accessed through a WiFi 802.11.a link. The wet-end is an 8-channel receiver which was used principally for MIMO communications in the 25-50 kHz band.
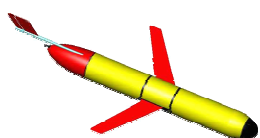

The Acoustic Oceanographic Buoy. This is an 8-phone free-drifting VLA designed and built by the University of Algarve (Portugal) and newly tested in Makai. It also can be continuously accessed through and 802.11.a WiFi link and provides broadband (0-25 kHz) signals. This system was unique in the experiment in terms of providing measurements over a large aperture of about 70 m.

University of Delaware Tripod Array. This is an autonomous (self-recording) 0-25 kHz 8-phone VLA. Besides providing another receive platform, this system is unique in providing a rigid structure that ensures array motion is not confused with intrinsic channel fluctuations. The system was original tested in KauaiEx but was significantly upgraded for the Makai Experiment with a quieter digital acquisition unit.
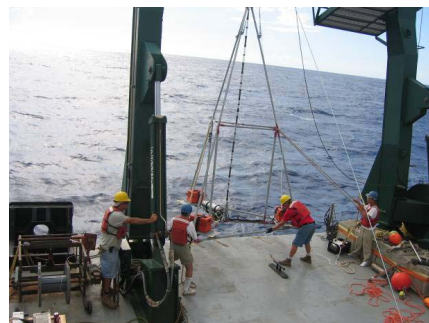
SLOCUM glider. This system was used to tow a horizontal line-array, providing the first demonstrations that a glider can be used for that purpose. A separate deployment phase was also done with the glider array in a vertical configuration. SPAWAR designed a custom low-power FPGA device to stream the acoustic data directly to a hard disk. Extensive work was done on materials testing to ensure a low-drag, low-noise array.
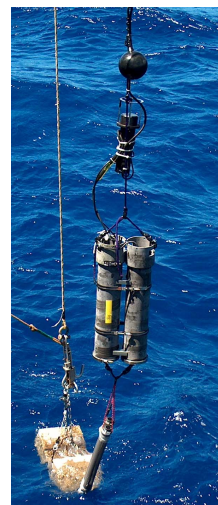
Telesonar testbeds. These are autonomous source/receive systems designed to test acoustic communications algorithms. These have continuously evolved over the last few years with major support from ONR's SignalEx program and they performed flawlessly during the experiment. One was fixed on the bottom, while the other was towed in a tow-frame to look at Doppler effects on acoustic communications.

MIMO source array. Funding for the source array was provided through ONR's SignalEx program described elsewhere in this volume. The whole system was newly developed this year and first tested at sea in the Makai Experiment. The inset shows the dry-end consisting of 6 trays, with five of the six trays containing a Boston Acoustics 200-watt car stereo amplifier and a pair of matching networks. The top tray contains custom electronics for streaming data directly from disk to each of 10 transmit channels at a rate of 200 kS/s per channel.

A vector sensor array from NSWC provided measurements of not just the acoustic pressure but the 3 velocity components of the field on a 20-channel (5 element) VLA of about 1-m aperture. The system was calibrated at Transdec prior to the Makai experiment.

The NATO Undersea Research Centre SLIVA array. This system (again newly developed and first tested in the Makai Experiment) was unique in allowing "beamformable data", that is, the array was

half-wavelength sampled over many wavelengths, allowing us to look at the arrival structure vs. angle.

UTAS RHIB array for LCS. This array is a longer version of the glider array that has been proposed for use on the Littoral Combat Ship and towed by an Autonomous Surface Vehicle.

Maule aircraft used as a high-Doppler sound source. This work is part of a project for rapidly measuring bottom properties under a separately supported ONR project. A separate MPL autonomous array was used to record the waveforms.
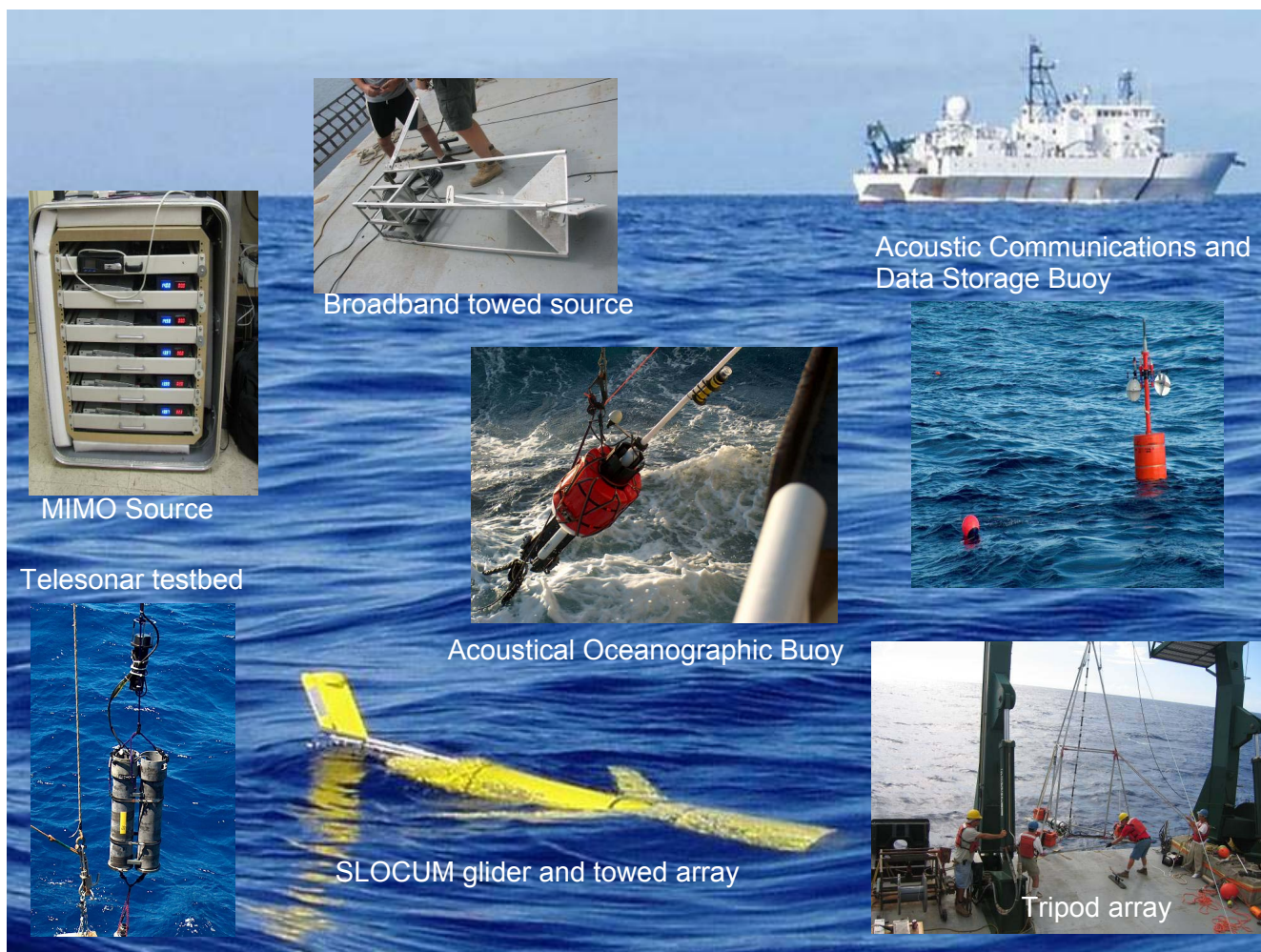

Figure 1. Selected components of the Makai Experiment.

RESULTS

As the Makai experiment was only recently completed, the data analysis is just beginning. Nevertheless, we can summarize preliminary results from the various groups.

MIMO testing: the MIMO communications was an unqualified success with both the new SPAWAR MIMO source array and the NRL ACDS receive arrays functioning flawlessly. In a 4x5 (4 transmitters and 5 receivers) configuration, the highest currently achieved data rate was 48 kbps.
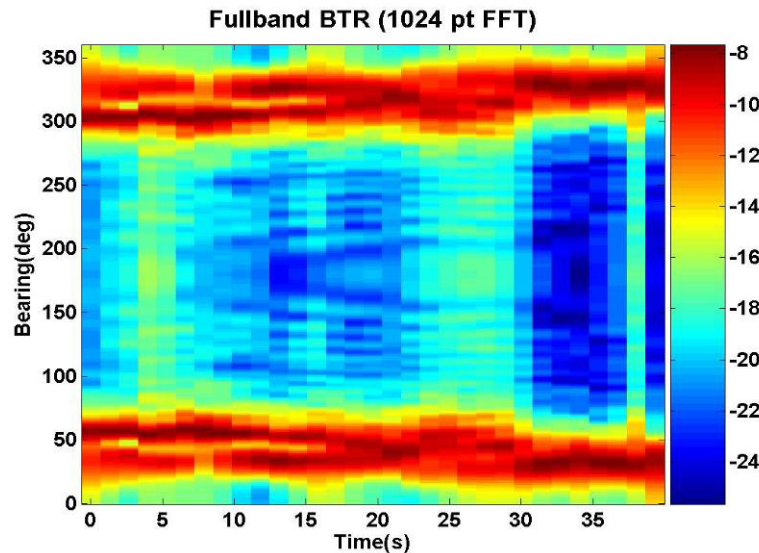

Figure 2. Bearing-time record showing a track of the target at a conical angle of about 60 degrees. The mirror image at 300 degrees is due to left-right ambiguity intrinsic to line arrays.

Glider operations: these tests also appear to have been 100% successful. The glider was deployed several times and demonstrated the ability to tow a horizontal line array. Scissor-grams, bearing-time records (Figure 2), and FRAZ (frequency-azimuth) displays were produced showing excellent array performance. Work is in progress to investigate signal gain degradation due to array deformation. Preliminary studies indicate that the array self-noise is very low.

Acoustic Oceanographic Buoy: This array was particularly important for the field calibration phase, intended to demonstrate that HF measurements could be extrapolated down to lower frequencies and then used for other applications. Data quality appears to be excellent. Figure 3 shows one example with the channel response measured at both high (left panel) and low (right panel) frequencies. As expected, both results show a very similar multipath structure. Work is in progress to demonstrate that the HF measurements can be used for LF depth classification.
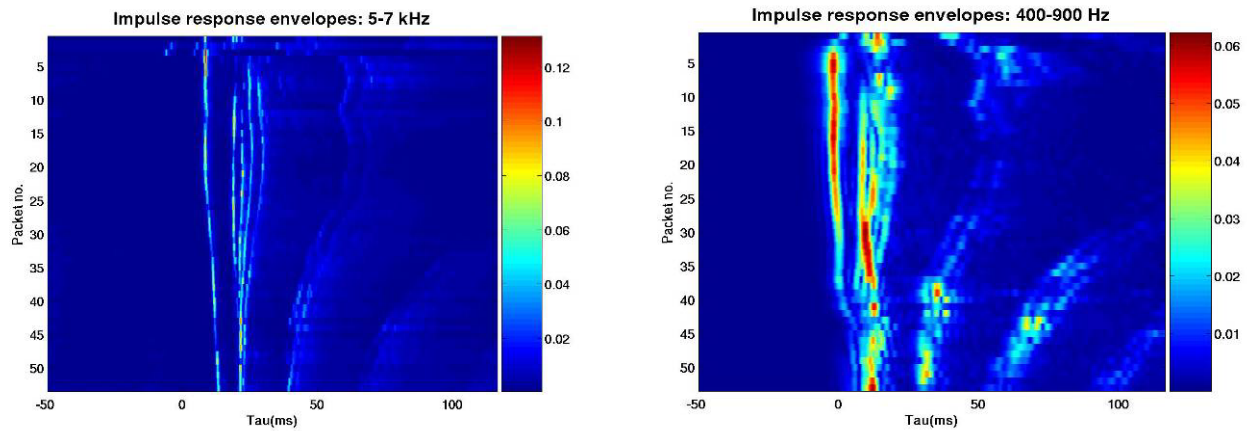
Figure 2. Channel impulse response as a function of source/receiver separation (packet number). The bright bands represent successive multipaths in the channel. The left panel was generated using a compact 5-7 kHz probe source which might be carried on an AUV. The right panel was done using a much larger low frequency (400-900 Hz) source and shows the anticipated similarity in the arrival pattern.

IMPACT/APPLICATIONS

There are a variety of Navy systems that operate in this frequency band. However, a key application of interests is acoustic modems. The MIMO testing is particularly valuable because of the large number of transmitters used in the source array and because of the variety of modulation schemes tested.

TRANSITIONS

This work is being conducted in parallel with the 6.2 SignalEx program (322OM) on underwater acoustic communication so that lessons learned about the basic propagation physics can be immediately linked to modem performance. The SignalEx program in turn transitions to operational modem development through other 6.3/6.4 navy programs.

RELATED PROJECTS

The Makai Experiment provided support for a variety of projects, including SignalEx, and PLUSNet.

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